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Practical Considerations for Overfilling Scenario Application

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Abstract

As a result of the BP Texas City explosion, industry recognized overfilling as one of the most important overpressure scenarios to be considered. Atmospheric release of flammable liquids above their flash point is no longer an accepted industry practice. Additionally, overfilling with combustible liquids often leads to mist formation, which may be easily ignited. Overfilling applicability is a critical factor in deciding whether to tie-in a relief system to a closed disposal system; for example, large liquid loads, especially those which are flashing, can affect knockout drum and flare capacity, radiation, etc.

This paper addresses practical considerations in determining if overfilling leads to overpressure. Subtle but important practical factors determine overfilling applicability, and the analysis requires an in-depth understanding of the process, instrumentation, and procedures. How the feed pressure reacts during overfilling must be carefully reviewed. Deciding if overfilling applies typically involves determining if an independent high-level alarm (IHLA) is present and whether there is adequate time for operator intervention. In some facilities, pressure transmitters are ranged to span the entire equipment height, giving additional redundancy in level alarms. As a result, an informal Layer of Protection type Analysis (LOPA) may eliminate overfilling as a source of overpressure, by serving to limit the maximum upstream feed pressure or serving as an IHLA. In some cases, the equipment will simply overflow to high capacity systems, such as a header system, such that no overpressure will occur. In other cases, the flow may have to fill multiple vessels; therefore, overpressure by overfilling is not credible based on multiple level alarms. These factors are each described and careful consideration can guide the overfilling applicability determination.

Keywords: Safety, Pressure Relief Analysis, Overfilling, Vapor Cloud Explosion

1. Introduction

In 2005 the BP Texas City refinery overfilled the raffinate splitter in the Isomerization unit during startup[1]. The relief valves discharged into a "blowdown drum with an atmospheric stack." The intent of the system was to allow vapor flashing off liquids to be vented at an elevated discharge location for dispersion and collect the remaining liquid. The use of a blowdown drum with an atmospheric stack was recognized as an antiquated practice but had not been routed to a flare system. The atmospheric blowdown drum was subsequently overfilled with liquid above the flash point.

The liquid above the flash point resulted in evaporation which increased due to droplet formation from liquid falling on equipment. The resulting vapor cloud was likely ignited by an idling truck resulting in the 15 fatalities and 180 injuries.

Two of the Chemical Safety Board (CSB) findings[2] can be summarized as:

- Potential for overfilling must be considered.
- Atmospheric release of liquids above the flash point is not accepted practice.

2. Applicable Codes and Standards

The applicable standard for evaluating overfilling for pressure vessels is API Std 521.

As a result of the 2005 Isom Explosion, API issued the API 521 5th ed 2008 Addendum[3] which added significant guidance on overfilling in §5.23 Overfilling Process or Surge Vessel. (The overfilling guidance was subsequently modified slightly and moved to §4.4.7 in the API 521 6th ed – 2014[4].) Key aspects are:

1) Startup and other non-normal modes of operation must be considered.

2) If the source of pressure can exceed the equipment design / relief device set pressure, options include, but are not limited to:

   <u>Eliminate overfilling with vessel design / relief device set pressure</u>
   - Ensure there is adequate margin between the relief device set pressure and maximum operating pressure, otherwise design the relief device and disposal system for the liquid release.
   - Consider the foundation, vessel design, and piping in overfilling.

   <u>Design the relief system for overfilling</u>
   - Ensure the relief device and disposal system can handle the liquid release.
   - Consider effects of two-phase flow and potential for autorefrigeration.
   - Consider the foundation, vessel design, and piping in overfilling.

   <u>Install a Safety Instrumented System (SIS)</u>
   - Safety Integrity Level (SIL) rating based on risk analysis.
   - Consider availability of instrumentation for SIS activation.

3) Evaluate the risk associated with discharge location (e.g. Atmosphere, process, flare.)

4) Considerations for level instrumentation include:
   - If safeguards are on different taps from process control system;
   - Susceptibility of instrumentation to common mode failures;
   - Tendency for level to show low or high when out of range;
   - Tendency for level to show low during overfilling; (e.g. Overfill top leg of dP cell.)
   - Impact of composition or temperature on density for dP cells;
   - Whether instrumentation is proven for the specific application;
   - Whether any instrumentation can span an extended range;
   - Whether instrumentation is suitable for non-normal operation.
   - Maintenance and testing frequency;

3. Other Industry Accepted Methods

It is common industry practice to exclude overfilling based on an independent high level plus adequate operator response time. Although it is easy to interpret this as a simplistic guideline that does consider the potential failure of operator intervention, the minimum acceptance criteria in context with API Std 521[5] is:

<u>To exclude overfilling based on an independent level alarm and operator intervention</u>
- Ensure an independent level alarm plus 10 – 30 minutes operator response time.
- Consider the availability and independence of instrumentation.
- Ensure training and procedures include expected behavior of instrumentation.
- Ensure operators agreement that procedures can be safely relied upon.
- Evaluate the risk associated with failure of operator intervention. Potential effects are included in Table 1:

Table 1: Potential Effects Associated with Discharge Location

Discharge Location	Potential Effects
Process	Other process relief
Flare	Backpressure, knockout drums, radiation
Atmosphere	Toxic or flammable release

The time for operator response must be determined by the owner operator based on the complexity of the operation and the time for the operator to diagnose / mitigate the problem. Factors should include the potential for “operator overload” due to multiple alarms in complex situations. Training must include written procedures and corrective actions.

Evaluating the risk associated with the failure of operator intervention is based on the operating company’s risk evaluation and acceptance criteria. The range of criteria include:
1) Evaluating the risk / potential overpressure when routed to a closed system.
2) Determining the layers of protection required for routing to atmosphere.

4. Summary of Commonly Accepted Overfilling Protection Practices

All of process design is ultimately geared toward the most cost-effective process design and most cost-effective risk reduction. In some cases, the risk is quite low and can be easily managed. In other cases, the risk-based engineering analysis is quite complex.

The order of preference of dealing with overfilling, given in Table 2, is generally:

Table 2: Order of Preference in Dealing with Overfilling

Mitigation	Preference
Eliminate overfilling with vessel design / relief device set pressure	Highest
Exclude overfilling based on company's risk acceptance criteria	↓
Design the relief system and disposal for overfilling	
Install a safety instrumented system (SIS)	Lowest

For new and existing facilities, the preference is to eliminate overfilling with the equipment design, if economically feasible.

If it is not economically feasible to eliminate overfilling by design, then the focus shifts to determining if the relief and disposal system is adequate for overfilling or if overfilling can be excluded with additional safeguards to meet the company's risk acceptance criteria.

It can be successively argued that overfilling is not applicable because of the nature of the system or the risk has been sufficiently reduced to meet the company's risk criteria in a variety of cases, including:

- Closed loop systems during charging and normal operation.
- Cases where overfilling (overflowing) will not cause overpressure.
- Cases where overfilling is so disruptive that it must be corrected to operate.
- Cases where overfilling cannot occur based on a thorough understanding of the pump calculations.
- Cases involving design changes to eliminate overfilling. (Inherently Safer)
- Cases where overfilling can be excluded by a PHA or LOPA.
- Cases where additional layers of protection have been added to exclude overfilling.

5. Closed loop systems

Closed loop systems are intended to operate with a fixed inventory circulating in a loop. Although seeming simple systems, extensive work is involved in designing a closed loop system. Besides designing for normal operation, the designer must also calculate the required charge and decide if the inventory will be stored in one vessel or if the bulk of the inventory will reside in the loop during maintenance.

During charging, overfilling / overpressure is generally not expected to apply if well-established procedures are followed.

During normal operation, overfilling / overpressure is also not expected. However, a systematic evaluation is required to ensure that upsets such as inadvertent closure of a block valve will not result in overpressure. Furthermore, if the intent of the design is to store the entire charge in one vessel, the inventory of the system versus vessel volume should be verified.

Examples of closed loop systems where overfilling is expected to be designed out of the system during startup / normal operation is given in Table 3:

Table 3: Closed Loop Systems – Overfilling Designed Out

Hot Oil System	Equipped with an expansion tank designed with “fill to cold” and “operating hot” levels. Overfilling due to thermal expansion is designed out.
Refrigeration	A refrigeration system is designed for a fixed inventory and charging is well-defined. Overcharging is designed out.
Amine Systems	The inventory of an amine absorbent system is well designed. Overfilling due to overcharging amine is typically not considered.

Consideration must be given to abnormal flow into the system causing overfilling. Possibilities include:

- Tube leak / broken tube scenarios
- Control valve failure cases

Examples of a control valve failure scenario that can cause overfilling is liquid hydrocarbon breakthrough to an amine treating or sour water

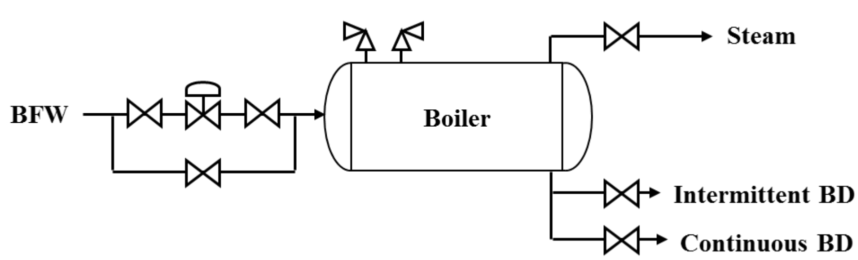
6. Overfilling (Overflowing) Will Not Cause Overpressure

In some cases, equipment is open to utility headers or downstream equipment; therefore “overfilling” (overflowing) will not cause overpressure.

Example 1: Normally Open Path to Downstream Header

A boiler is typically open to the downstream steam header. A simplified boiler is shown in Figure 1.

Figure 1: Simplified Boiler



ASME Section I[6] prescribes the relief system design requirements as the design steaming rate of the boiler. The underpinnings are that for BFW feed control valve fail open or inadvertent opening of the bypass, the boiler is open to the header.

Similarly, for process steam generator built according to ASME Section VIII[7] and the potential overpressure evaluated by API Std 521[8], the BFW feed control valve failing open (or inadvertent opening of the bypass) and the outlet being blocked at the same time is typically considered "double jeopardy."

A brief pressure relief analysis of a boiler in given in Table 4.

Table 4: Typical Boiler Pressure Relief Analysis

Scenario	**Relief System Design Basis?**	
Blocked Outlet (Steam)	Yes	Normal steam flow
Blocked Outlet (C-BD)	No	Slightly wet steam to header
Blocked Outlet (I-BD)	No	NC - Intermittent use
Control Valve / Bypass	No	Overflow to the header

Different companies have different policies on how to treat overfilling in these situations:

- Assume the path to the header is adequate.
- Perform hydraulics to ensure the path to the header is adequate.
- Design the relief system capacity for overfilling.
  (Discharge of relief system must be routed to a safe location.)

When credit is taken for flow to the header, a hydraulic analysis should be considered to ensure the path is adequate without exceeding allowable accumulation. In addition, the steam line should be supported for liquid / two-phase flow.

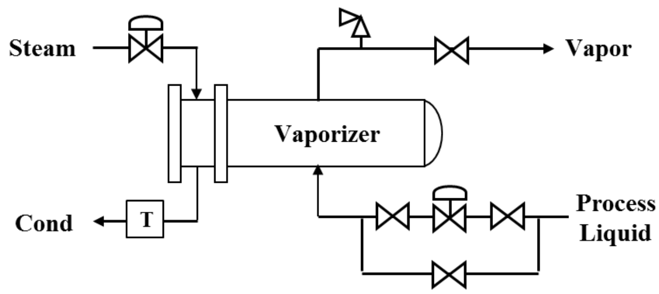
A common position is that the boiler feedwater will flow to the steam header and the relief valves on the boiler will not lift. The steam header is typically quite large compared to the capacity of an individual BFW control valve failing open. A good case can be made that the "overfilling" (overflowing) of the boiler will be detected via the effects on the operation of the steam system (i.e. loss of heat transfer in the process, rotating equipment stops working, etc.) long before overpressure occurs.

Damage can occur due to steam hammer and liquid flowing into turbines. However, the damage cannot be prevented with a relief valve. Minimizing equipment damage is typically considered part of Loss Prevention.

Example 2: Vaporizer Normally Open to Downstream Header

Another common example of a piece of equipment that is open to a downstream equipment or distribution header is a process vaporizer. A common vaporizer is shown in Figure 2.

Figure 2: Process Vaporizer



The minimum relief system design basis for a vaporizer that is normally open to the header is the vapor generation rate for blocked outlet.

The process feed control valve failing open, inadvertent opening of the bypass, loss of heat input, or a broken tube are overfilling concerns, but the vapor valve being blocked-in at the same time is typically considered double jeopardy.

When credit is taken for flow to the downstream equipment, a hydraulic analysis should be considered to ensure the path is adequate without exceeding allowable accumulation. In addition, the vapor line should be supported for liquid / two-phase flow.

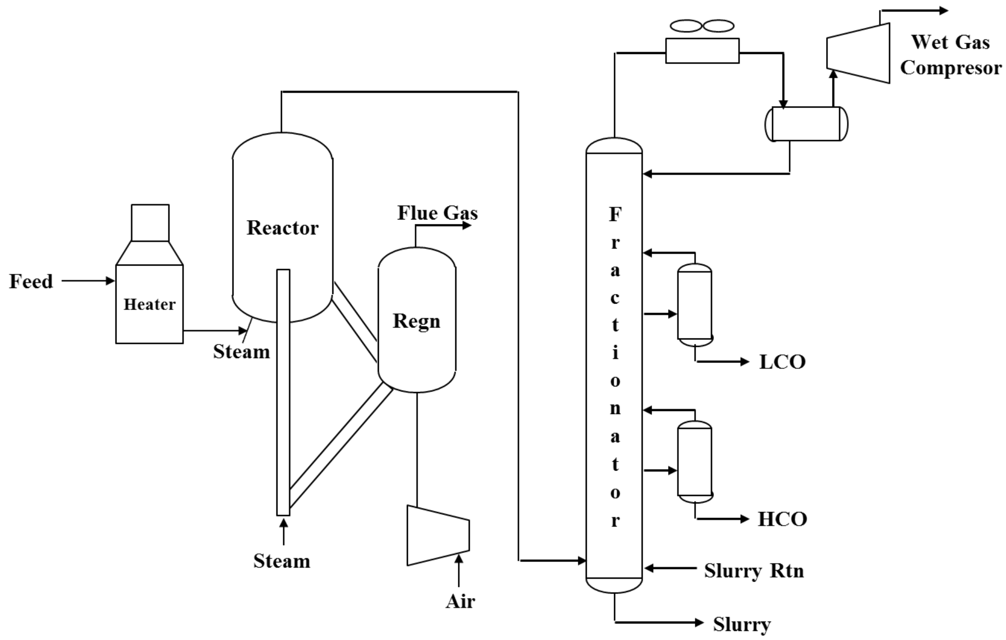
Whether the downstream system can absorb the additional flow must also be considered. If the downstream system cannot absorb the additional flow, the relief system on the vaporizer or downstream system must be designed for the additional flow.

7. Overfilling is So Disruptive that it Must be Corrected to Operate

In some cases, the owner operator may decide that the onset of overfilling is so disruptive that the process cannot continue to operate and must be shutdown.

Example 3: Overfilling is not Possible Based on System Behavior
An example of a system where it might be argued that overfilling is not credible because it is so disruptive to the process is a Fluidized Catalytic Cracker (FCC) – Main Fractionator. A significant part of the driving force of the process is the air blower to the regenerator. If the main fractionator were to try to overfill the blowers must support the entire column of liquid which also has the effect of backing out the air blowers which is a major upset to the process. A simplified FCC – Main Fractionator is shown in Figure 3.

Figure 3: FCC Main Fractionator



Discussions with engineering and operations on potential for overfilling of a Fluidized Catalytic Cracker – Main Fractionator can be summarized as:

> "The effects of the Main Fractionator starting to overfill are so obvious that the unit cannot keep running. We must shutdown and restart."

This reflects a complex understanding of the operation including high levels in multiple vessels, higher pressure drop through the process causing the air blower to back out, etc.

The decision that overfilling can be excluded on the basis that the effect on the process is so obvious that the process cannot continue to operate must be made by a qualified individual (e.g. superintendent) or preferably a group knowledgeable in the operation of the unit and documented accordingly.

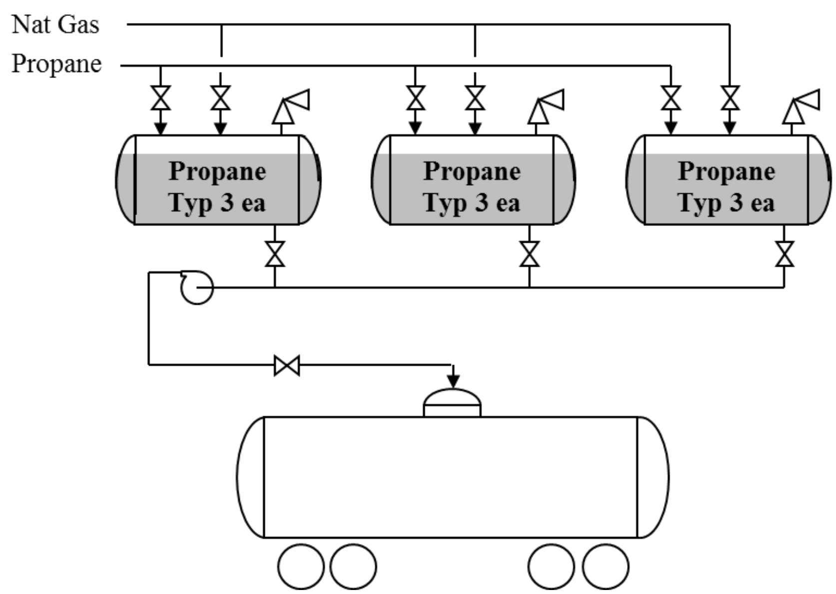
8. Overfilling Cannot Occur with Thorough Understanding of Calculations

Most overfilling cases involve pumps. A key aspect of evaluating overfilling is understanding how the upstream pressure reacts when the pump is effectively deadheaded into a downstream system.

<u>Example 4: Pumps with a Well-Defined Maximum Upstream</u>

Some pumps will have a very well-defined maximum upstream pressure. An example is a rail car, tank car, or transfer operation. See Figure 4.

Figure 4: Loading Operation with Well-Defined Upstream Pressure



$$Pump\ Discharge\ P_{Max} = P_{Normal} + \frac{\rho}{144}\left(\frac{g}{g_c}\right)(H_{Deadhead} + H_{Static})$$

Observations

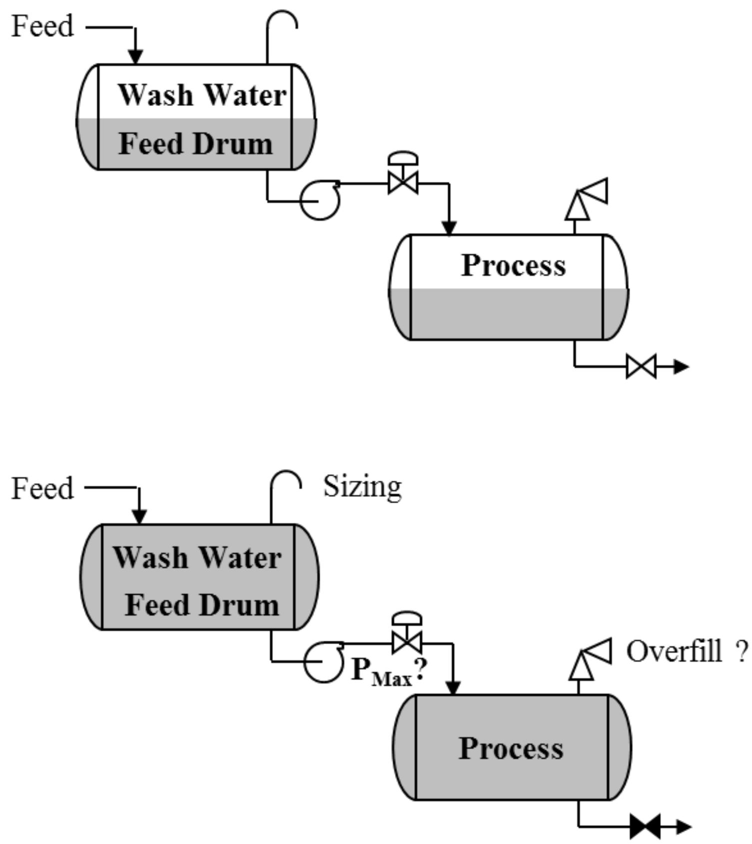
- It is unusual to feed into and pump out of storage vessels at the same time for inventory control purposes. (e.g. Low-pressure tanks, bullets, spheres.)
- Inadvertently blocking the flow to the rail car loading operation will not result in overfilling of the bullets. (Overfilling may apply for other modes of operation.)
- Railcars and tank cars are equipped with relief devices.
- The maximum discharge pressure of the loading pumps is based on the highest normal operating pressure of the bullets. (In cold climates, the bullets may be padded with natural gas in the wintertime.)

It is expected that rail car and tank car loading operations are "inherently safer" designs such that the maximum pump discharge pressure cannot exceed the pressure rating of the rail car or tank car but must be verified with a thorough understanding of the loading operation.

Example 5: Pumps Associated with Vessels with Open Vents

Calculating the maximum pump pressure associated with a vessel with an open vent can be deceptive. In the case of a basic API 650 tank, the maximum static head is well defined. Occasionally, a pressure vessel will be equipped with an open vent. The observer might be tempted to assume the vessel is at "atmospheric pressure." However, there is a maximum feed pressure/sizing basis for the open vent which must be taken into consideration. See Figure 5.

Figure 5: Maximum Upstream Pressure with an Open Vent



$$Pump\ Discharge\ P_{Max} = P_{Relief} + \frac{\rho}{144}\left(\frac{g}{g_c}\right)(H_{Deadhead} + H_{Static})$$

<u>Observations</u>

- Feed drum will overfill.
- The potential for overpressuring the process depends on the pressure used for sizing open vent.

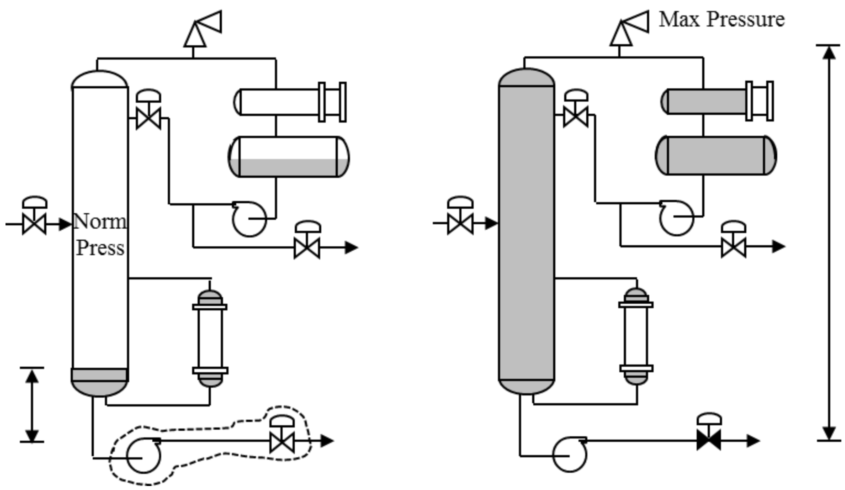
In this case, inadvertently blocking the outlet of the process will back the pump up the curve. The feed drum will overfill. The potential for overpressuring the process can depend on the sizing basis of the open vent.

It is possible to have a case where the downstream vessel relieves moving the pump back out on the curve / lowering the suction pressure such that the system will oscillate between relieving upstream and downstream. The preference is to size the open vent (and choice of the pump) so the wash water drum will relieve water instead of the process relieving for an “inherently safer” design.

Example 6: Complex Overfilling Considerations

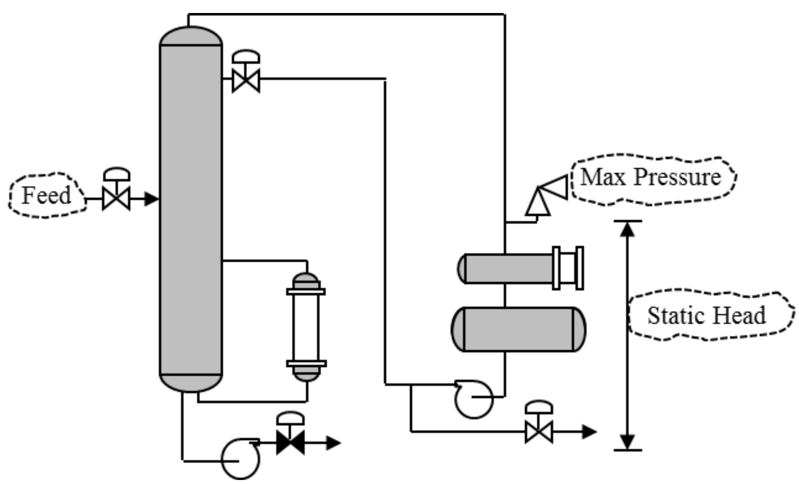
Overfilling of a column system entails filling the entire column system. This example assumes the initiating event is the bottoms control valve failing open. See Figure 6.

Figure 6: Overfilling of a Distillation Column



Assumptions that should always be checked in determining the maximum discharge pressure of the pump include considering relief valve location / sizing basis and how the feed pressure / flow will react when the column pressures up. See Figure 7.

Figure 7: Factors Involved in Bottoms Pump Discharge Pressure



Factors include:

Feed
- How does the feed flow rate change?
- How does the feed pressure change?

Static head Considerations

- Is the column relief device located on the overhead line near the top of the column or close to the condensers?

Maximum Relieving Pressure

- Is the relief device set at limiting MAWP or lowered to account for static head?
- If relief device is located below the top of the column, did sizing include the additional pressure from static head for overfilling? (Rare)
- Will overfilling result in a loss of cooling plus continued heat input?

Ultimately

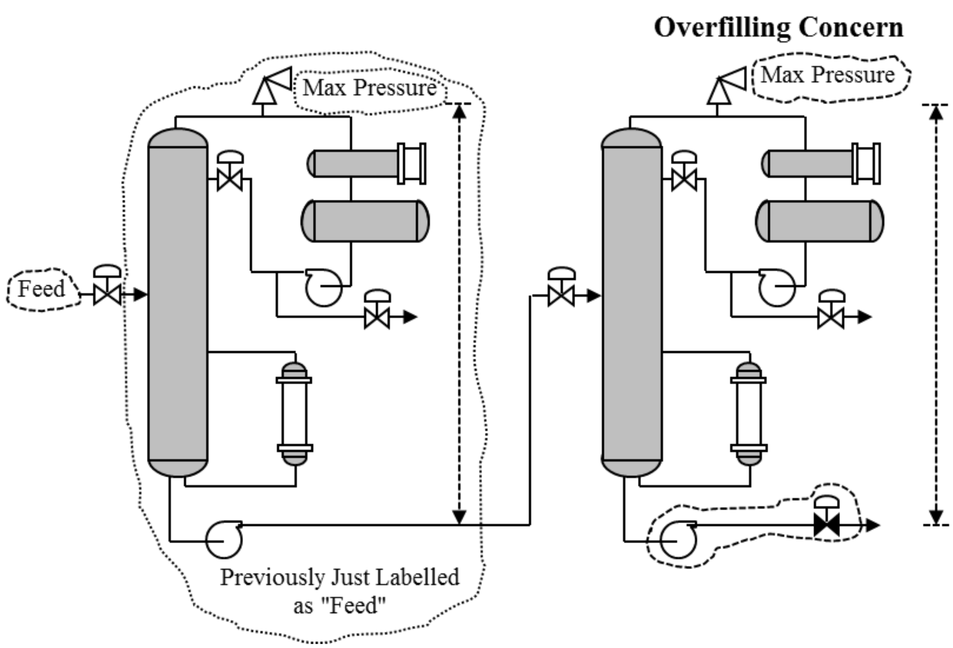
- Can a lower relieving pressure be justified?

  If the relief system is oversized:

  - Can one device be used instead of multiple devices?
    (10% versus 16% accumulation)
  - Is the device a pilot?
    (Full open at set pressure = Calculated accumulation versus 10% accumulation.)

A seemingly "basic" overfilling concern can involve significant complexity in determining how the upstream pressure will react, static head, and set pressure considerations. Consider multiple columns in series. See Figure 8.

Figure 8: Multiple Columns in Series:



Observations

- Credit can potentially be taken for forward flow for both sets of overheads pumps.
- The first system could potentially relieve before the downstream column relieves.

− The static head included on the bottoms pump for the first column is partially offset based on the static head to the relief device on the second column.
− Elevation of the equipment and static head effects are not included in this example.

Conclusions

1) A seeming basic overfilling scenario can be quite complex.
2) If the relief device and disposal system are inadequate based on easy assumptions, the pump discharge flowrate and pressure can potentially be significantly refined.

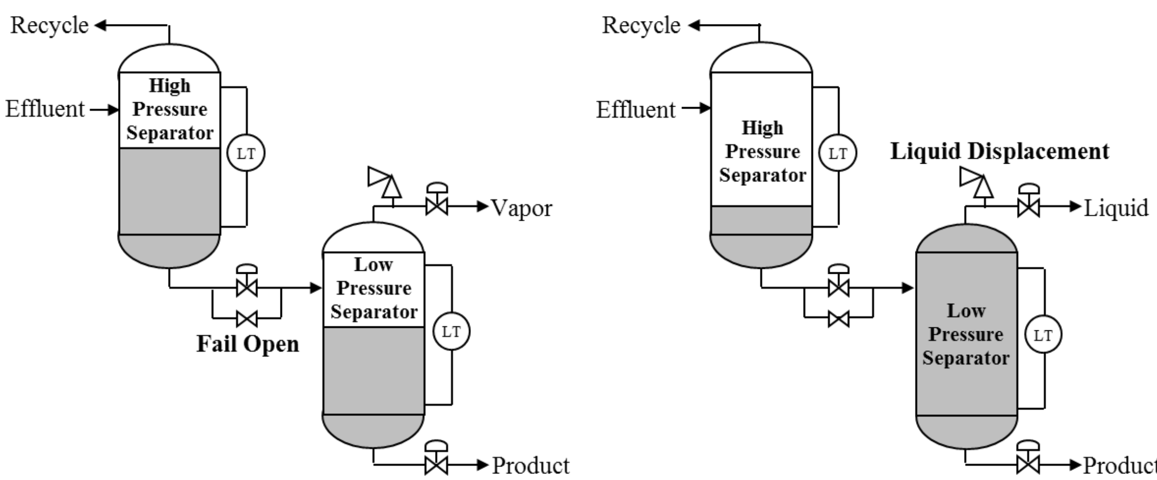
9. Changing the Design to Eliminate Overfilling (Inherently Safer)

If a relief valve discharges to atmosphere or the relief device / disposal system are inadequate for overfilling, a valid approach is permanently changing the operating envelope to eliminate overfilling:

Example 7: Excluding Overfilling of a Low-Pressure Separator

A common design criterion in the design of a hydrotreater is to ensure the high-pressure separator cannot overfill the low-pressure separator when the high-pressure letdown valve fails open or the bypass is inadvertently opened. If the low-pressure separator is full of liquid and high-pressure gas enters the system, liquid will be displaced at the vapor volumetric expansion rate. This is known as “liquid displacement” or “bottom venting.” The required relief area for displacing liquid at the vapor volumetric rate can easily be 10 times higher than expected for the vapor by itself even if credit is taken for continued outflow through the vapor and liquid control valves from the low pressure separator in their normal position with no credit for positive response by the control system. See Figure 9.

Figure 9: Control Valve Fails Open Resulting in Liquid Displacement.



Besides simply preventing the low-pressure separator from becoming liquid full, the preference is to limit the maximum level to ensure the relief system is adequate based on 2-phase disengagement models and a check for liquid re-entrainment.

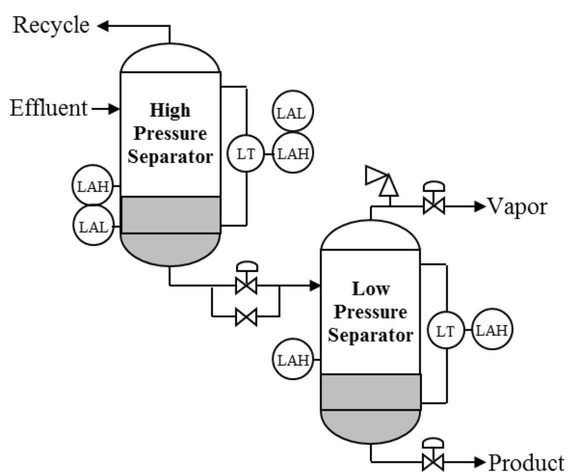
In one case, the high-pressure separator was replaced with a larger vessel, but the low-pressure separator was not. The relief system was significantly undersized for liquid displacement.

This case involved extensive discussions with operations with two objectives:

1) Avoid potential liquid displacement and otherwise limit the maximum level in the low-pressure separator to ensure the relief system is adequate when 2-phase disengagement and the potential for liquid re-entrainment is taken into consideration.
2) Minimize the potential to inadvertently lose level in the high-pressure separator causing vapor displacement (also known as "gas blowby") even through the relief system was adequate.

The agreed upon changes were additional independent instrumentation to include both high, high-high, low, and low-low level alarms. Although the changes can be viewed as a layer of protection analysis, the better understanding is a permanent shift in the operating envelope to eliminate potential overfilling for the low-pressure separator. See Figure 10.

Figure 10: Change Operating Envelope to Exclude Overfilling / Liquid Displacement



Other cases that were considered separately:

- Gas blow-by (vapor based on disengagement models)
- Blocked outlet (two-phase)

10. Overfilling Excluded with a PHA or LOPA

A Process Hazard Analysis (PHA) is a team of qualified individuals from engineering and operations. Based on an in-depth review of the system, a PHA team may include or exclude overfilling as a relief system design scenario based on the collective knowledge of the team.

Example 8: Excluding Overfilling of a Hydrotreater by a PHA

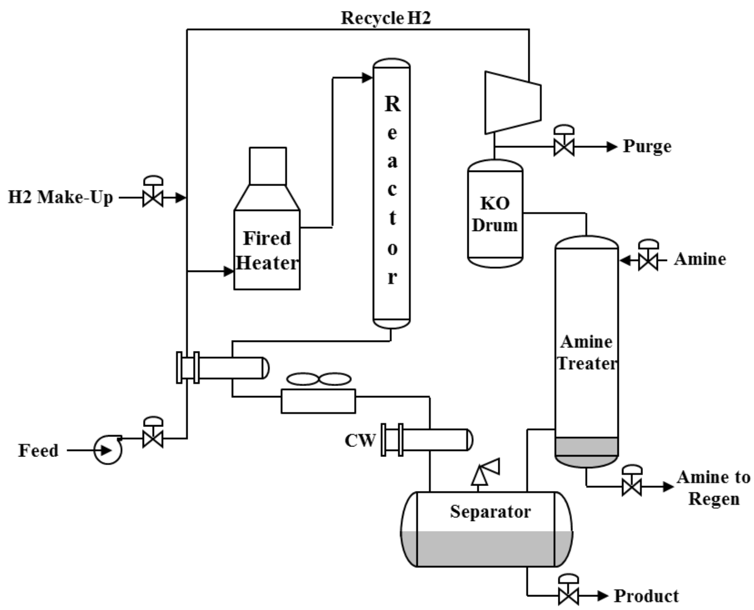
Hydrotreating and hydrocracking are two similar but separate processes under the broad category of hydroprocessing.

Hydrotreating removes impurities such as sulfur (to hydrogen sulfide H_2S) and nitrogen (to ammonia). In addition, some cracking generating to methane occurs. In the process, olefins are saturated which raises the octane rating of gasoline and cetane rating of diesel.

Hydrocracking breaks larger molecules into smaller ones.

There are several configurations but both processes involve reacting the material at high pressure and temperature with hydrogen in the presence of a catalyst. A basic hydrotreater design is shown in Figure 11.

Figure 11: Basic Hydrotreater



The reaction is sometimes liquid phase and sometimes supercritical depending on the design. The combined feed to the fired heater and flow after the cross exchanger is 2-phase.

Assuming the charge pump is capable of overpressuring the system, the relief system is often designed for overfilling for blocked product outlet from the separator. How to handle the hydrogen is a discussion issue.

Recycle Hydrogen
Some companies include the recycle hydrogen. Other companies consider the recycle compressor as stopping; therefore, the recycle hydrogen stops.

Make-Up Hydrogen
The make-up hydrogen is largely consumed but some H_2S, ammonia, and methane is generated. Since the process is no longer operating normally, the most common design

basis is to include the make-up hydrogen with the product flow as if no hydrogen is consumed.

Even a basic hydrotreater is a still a large complex process. If the relief or disposal system is inadequate, a valid question is:

> "Is overfilling a relief system design scenario based on levels in multiple pieces of equipment, the behavior of the process, etc.?"

The results from a PHA team from engineering and operations on potential overfilling of this hydrotreater can be summarized as:

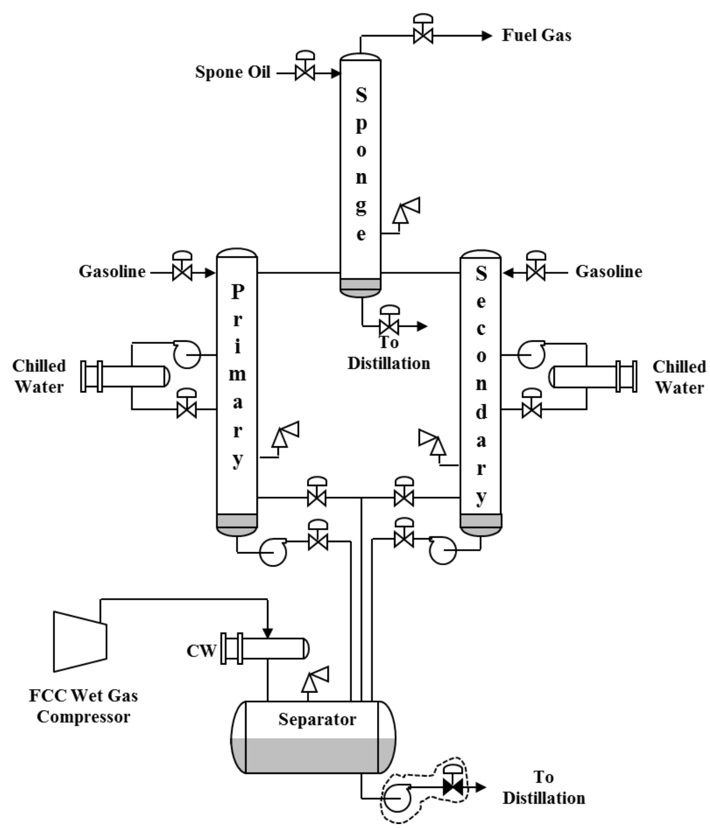
> "Overfilling / overpressure of the hydrotreater will not occur because of multiple level indications, the behavior of the equipment, and calls from downstream unit losing feed."

This reflects an understanding of the complex behavior of the unit and the layers of protection to prevent overfilling.

Example 9: Excluding Overfilling Light Ends Unit by a PHA

One type of Vapor Recovery Unit after the Fluidized Catalytic Cracker involves absorbing the cracked gases as shown in Figure 12.

Figure 12: FCC Absorption Vapor Recovery Unit



Overfilling of this system due to blocked liquid outlet of the separator would require overfilling four vessels, with the associated high-level indications from each vessel and the associated process upsets. The pressure in the equipment would only build due to static head and some additional pressure drop until the liquid finally reaches the control valve to the fuel gas system. Once the liquid finally reaches the control valve to the fuel gas system, the pressure would spike, and overfilling / overpressure would occur.

Blocked liquid outlet of any of the other liquid paths requires overfilling of at least three vessels with the associated high-level indications. (The vapor control valves are much larger than the liquid control valves. The separator and its level instrumentation would typically also be involved.)

A PHA team consisting of engineering and operations personnel decided that the risk of overfilling was sufficiently low that overfilling was not a relief system design scenario for overpressure protection.

11. Adding Layers of Protection to Exclude Overfilling

In the event the PHA includes overfilling as a relief system design scenario, an option is a Layer of Protection Analysis (LOPA). A LOPA also consists of qualified team to quantitively assess the risk, determine the number of layers of protection present, and the number of layers required to reduce the risk to the owner operator's risk acceptance criteria.

Layers of protection could range from adding an independent high-level alarm (IHLA) to a Safety Instrumented System (SIS) with a Safety Integrity Level (SIL) to add a sufficient number of layers based on the probability of failure on demand.

If no independent high-level alarm is present, adding one could provide one layer of protection with credit for operator response. However, if a high-level alarm is already present, then simply adding another one typically does not add another layer because the operator is in common. For additional credit, entire layers of protection must be added.

In the case where there are multiple alarm points present, a written management system which includes training of additional outside operators, inside operator, and/or the shift foreman to respond to different alarm points if corrective action hasn't been taken may constitute additional layers of protection. Factors that would be included are evaluation of the response times, the corrective actions to be taken, actions to be taken during loss of communication with the primary outside operator, etc.

Example 10: Adding Layers of Protection to Exclude Overfilling

After the Isom explosion (referred to in Section 1) some companies recognized:

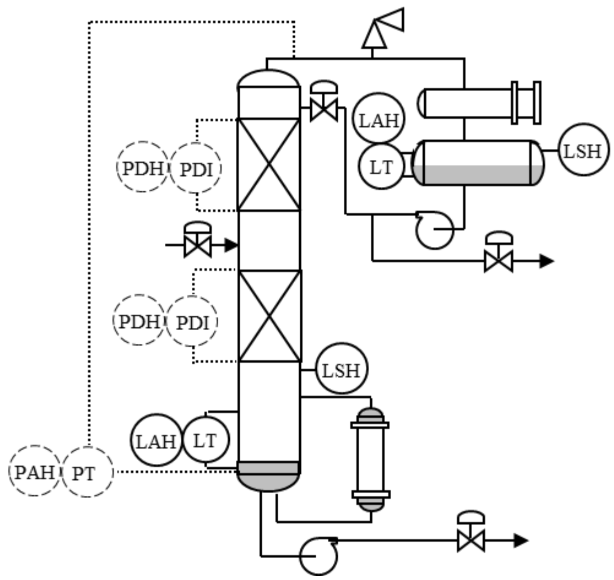
- An independent high-level alarm was not present or subject to common mode failure.
- The range of level transmitters were only intended for normal operation.

As a result, one of the strategies used a (LOPA) type analysis to ensure the level would always be detectable and provide multiple indications of overfilling. See Figure 13.

Changes often included:

1) Adding differential pressure transmitter spanned for the entire height of a column to ensure the level was always detectable if the level overfilled the high tap on the normal dP cells used for level control instrumentation.
2) Adding high level alarms
3) Using high differential pressure alarms over beds to provide multiple indications of potential overfilling.
4) Implementing level deviation alarms comparing level instrumentation with level information predicted from the differential pressure instrumentation.

Figure 13: LOPA Implementation to Reduce Risk of Overfilling



12. Conclusions

1) Overfilling typically does not apply to Closed Loop Systems.
(A systematic analysis is still required.)

2) Overfilling to a utility system will typically not result in overpressure.

3) Overfilling to other process equipment may not result in overpressure.
(The ability of the downstream system to absorb the flow must be checked.)

4) In some cases, the onset of overfilling is so disruptive it can be excluded as a scenario.

5) Pump discharge pressure calculations require a thorough understanding of the system.

6) A PHA or LOPA may exclude overfilling as a design scenario.

7) Additional layers of protection can be added to excluding overfilling as a scenario.

8) The preference is to design out overfilling with equipment design. In some cases it is possible to ensure the operating envelope is so narrow that overfilling is not a scnenario.

13. References

[1] CSB: U.S Chemical Safety Board (2007) Report 2005-04-I-*TX Refinery Explosion and Fire*, Available https://www.csb.gov/assets/1/20/CSBFinalReportBP.pdf p.17.

[2] Ibid, p. 21 - 23

[3] API Standard 521:2008, *Pressure-relieving and Depressuring Systems, p. 65-66*

[4] API Standard 521:2014, *Pressure-relieving and Depressuring Systems, p. 21-22*

[5] Ibid, *p. 13*

[6] ASME BPVC, Section I:2017*, Rules for Construction of Power Boilers, p. 61*

[7] ASME BPVC, Section VIII Div 1:*2017, Rules for Consruction of of Pressure Vessels*

[8] API Standard 521:2014, *Pressure-relieving and Depressuring Systems, p. 13*